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Final Report, Contract No. ARDS-628

COMPARATIVE COST ANALYSIS OF MICROWAVE AND WIRELINE RADAR REMOTING TECHNIQUES

March, 1963

Project Number 151-1S

Prepared for

FEDERAL AVIATION AGENCY
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

By

SYSTEMS ANALYSIS AND RESEARCH CORPORATION
Boston - Washington

FINAL REPORT, CONTRACT NO. ARDS-628

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This report has been prepared by Systems Analysis and Research Corporation for the Systems Research and Development Service, Federal Aviation Agency, under Contract No. ARDS-628. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA.

SYSTEMS ANALYSIS AND RESEARCH CORPORATION
Boston-Washington

Systems Analysis and Research Corporation, Boston-Washington
COMPARATIVE COST ANALYSIS OF MICROWAVE AND WIRELINE RADAR REMOTING TECHNIQUES
Prepared by John W. Drake and Robert L. Schein, March 1963, 68 pp. includ. 22 tables, Final Report,
(Contract Number ARDS-628)

ABSTRACT

The objective of this report is the comparison of the cost to the FAA, of wireline remoting of digitalized radar and beacon data (and beacon only) to Air Route Traffic Control Centers with the costs for microwave remoting of the same information in analog form. The second technique includes facilities for subsequent converting of the data to digital form at the center. The costs considered are those not yet sunk or committed, i.e., future costs. Costs for both methods alone, and for a mixed system, are developed for each of two nationwide remoting networks - that presently programmed including new links for which the FAA may be committed through F.Y. 1964, and a hypothetical network to provide radar coverage to 5,000' MSL or 3,000' above the terrain, whichever is higher.

Costs are developed for each microwave repeater and terminal pair of each link, based on individual variations in terrain and hardware requirements.

For FAA/Air Force joint use sites which now have Air Force AN/FST-2 computers, various alternatives are investigated including modifying the AN/FST-2 to provide the FAA its required output, installing an FAA-tailored, modernized, solid-state radar processor alongside the Air Force T-2, or installing the FAA machine instead of the T-2 if it could also meet the Air Force's needs. Wireline costs were developed under the assumption that the FAA would pay all costs for any remoting equipment which it shares with the Air Force. The alternative assumption that the FAA and Air Force would share operating and maintenance costs equally was also explored.

The investigation concludes that the difference in cost between the two transmission methods is small. Where a difference does exist it generally favors the wireline technique. In cases of extreme link length and/or very difficult terrain, wireline is considerably less costly. For the great majority of all other links, if non-cost considerations are of any appreciable importance, costs should probably not govern any ultimate decision.

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MAJOR ASSUMPTIONS AND CONCLUSIONS

The conclusion of this study can be properly understood only in the light of the study's important input assumptions. These will, therefore, be summarized briefly here before setting down the conclusion.

Assumptions:

1. Costs would be calculated and included in the comparisons made, only if not yet incurred or committed. The costs developed were, therefore, to represent as closely as possible the new obligations which would be required to implement the alternative new programs.

2. For joint-use sites (with the Air Force) the most unfavorable assumption from the FAA's standpoint is made; that the FAA pays for all costs of remoting equipment it shares. Other assumptions concerning cost sharing have been costed out, but the final conclusions concerning the relative cost of wireline are based on the assumption stated above which tends to maximize wireline costs.

3. No cost adjustments are made for the possible sharing of either microwave or wireline circuit expenses with other services or agencies; that is, the radar remoting problem is costed entirely by itself.

4. Costs for the complex radar and beacon data processors are based on the assumption that they would be ordered in quantities ranging upwards from 20 or 25 units. Were the number of units desired to be very small for some reason, it is doubtful that they could be had for the price indicated.

5. Though microwave remoting makes both processed and unprocessed raw radar available at the ARTCC if desired, wireline does not; however, no cost is assigned to this difference in service rendered.

CONCLUSION:

For remoting of radar and beacon data or beacon data alone to ARTCC's from ARSR's and distant ASR's wireline shows itself as the cheaper method for the future in the majority of cases. Based on the link-by-link costs developed, however, retention or installation of new microwave links would sometimes prove the least expensive. It

can only be concluded, therefore, that for any link for which a clear and unassailable requirement for raw radar video does not exist, wireline and microwave cost estimates should be prepared in detail and the decision made only after thorough study of both.

As is stated above, the two methods' costs are such that though for some links wireline appears cheaper; for others, microwave appears less expensive. Further stated, the costs are of such a character as to make the cross-over very gradual; that is, though one or the other is cheaper in each case, in only a small fraction of the total cases, those at the extremes, is the difference very large. Since the costs on which the comparisons are based are in a very real sense estimates with an inherent margin of error, it is probable that for many of the links the cost differences indicated fall within the limits of the estimates' error, i.e., they are "in the noise". Thus, it may be concluded that if non-cost considerations for such links are of any appreciable importance, costs should probably not govern the ultimate decision. Table I summarizes the annual costs of the alternative systems.

The results of the study are system costs as follows:

TABLE I*

ANNUAL COSTS INCLUDING AMORTIZATION OF NEW CAPITAL EXPENDITURES
(in millions)

	Radar and Beacon		Beacon Only	
	Presently Programmed System	Hypothetical System	Presently Programmed System	Hypothetical System
All-Microwave	$18.5	$24.9	$17.4	$23.3
All-Wireline	15.3	21.7	14.1	20.1
Mixed Least Cost	15.0	20.7	13.8	19.1

NOTE:

Subsequent to the completion of this report a much more detailed investigation into the operation and maintenance costs of the proposed FAA solid state processor and a proposed modification of the existing AF/FST-2B was conducted by a joint FAA/DOD task force ("A Study of the Use of SAGE Facilities for Air Traffic Control Purposes;" January, 1963, CONFIDENTIAL). The following table compares the costs developed by that study with those adopted for use in this report:

	FAA/DOD	SARC
Modified AN/FST-2B (duplex)	$208,000	$169,000
New FAA/FST-2 (duplex)	$ 98,600	$125,000

The adoption of the FAA/DOD cost estimates would lend additional validity to the conclusions which may be drawn from this report concerning the cost relationships between the microwave and wireline transmission techniques.

INTRODUCTION

This project was initiated to provide a detailed analysis of the costs of alternative methods of radar remoting. This interest area was explored in more general terms in "Techniques and Costs of Radar Remoting," prepared by SARC for Traffic and Economic Analysis Area, Systems Management Division, Systems Research and Development Service, FAA, July 1962 (ARDS-549).

The earlier study examined the several currently practicable methods of remoting primary and secondary radar information from radar sites to Air Route Traffic Control Centers (ARTCC). Particular emphasis was given to (a) information content, (b) reliability, and (c) cost. The cost area was treated on an average basis, and did not allow for the many variables which may affect the cost of an individual installation.

The first report pointed up of the need for more detailed and specific cost comparisons applied to system designs under actual consideration.

STATEMENT OF PROBLEM

According to the contractual work statement this project was to accomplish the following tasks:

> "Develop estimates of systemwide costs of remoting primary and secondary radar data from two national configurations of radar sites by two alternative configurations of remoting links. In each of the alternative methods the remoted data will be converted to a form acceptable to a digital computer."

The two national configurations to be considered in this analysis are:

1. The configuration of long-range surveillance radars presently progammed through fiscal 1964. (Case I)

2. A hypothetical configuration of radar sites to obtain coverage down to 5,000 feet MSL or 3,000 feet above terrain, whichever is higher. (Case II)

For the first configuration the costs for both an all-microwave remoting system and a least cost combination (if applicable) wireline/microwave network will be developed; for the second configuration only the least cost system will be required.

GENERAL DISCUSSION OF RESEARCH APPROACH

The general research approach and costing technique reflect, in addition to the explicit constraints of the contractual work statement, an implication that these cost comparisons are to be used in decision-making.

Specific stipulations were made in the contractual work statement concerning the treatment of certain costs. The following passage discussing these considerations is extracted verbatim from this statement:

> "In all estimates, existing equipment shall be considered sunk costs unless they are to be replaced, in which case they shall be assigned a reasonable salvage value. If equipment removed from one site may be advantageously employed at another location, it may be consigned; however, costs shall be estimated for removal, movement and reinstallations."

Since all costs associated with the presently programmed system already expended are to be considered sunk1/ the comparison for this configuration reduces to the comparison of the operation and maintenance cost of the all-microwave system with the total cost of the wireline system.

1/ This "sunk" cost concept was considered to apply to the entire FAA all-microwave system as planned through fiscal year 1964. This assumption tends to understate the annual assignable costs for the Boston area links, the Condon-Seattle link, the Tonopah and Fallon to Oakland links, the Houston-Minneapolis link, Traverse City-Chicago, Tampa-Miami, Dauphin Island-Jacksonville, Tyndall AFB-Jacksonville, Detroit-Cleveland, the Houston area links with the possible exception of San Antonio which may be salvageable, Amarillo-Albuquerque, Phoenix-Albuquerque, El Centro-Los Angeles which probably will be developed as a commercial link, Cape Charles-Washington which also may become a commercial link,and Cedar City-Los Angeles. The foregoing links are understood, at the time of this report, not to have been absolutely fiscally committed; therefore, their costs are probably understated by the amount of annual amortization of construction and installation not yet "sunk."

In the second configuration (coverage to 5,000' MSL) the amortization of the construction and installation cost for only the added links was assigned. Thus, for both configurations the cost indicated for the microwave links is less than the total investment by the amount of the sunk costs not included. For the intended purpose, this is believed to be consistent with the requirements of a meaningful analysis. There is no particular need for an estimate of the total projected investment including past expenditures. What is needed for current decisions is an estimate of future expenditures necessary to produce working systems. This estimate is the product of this study.

Since microwave is the present FAA standard and no purpose would be served by substituting for it a new system which offered no particular advantage, there was a conscious effort made in this study, when confronted with more subjective decisions, to tip the scales slightly in favor of the microwave, that is, in favor of the status quo, by making it more difficult for the challenging system to demonstrate its economic superiority. It was felt that if the wireline costs worked out to be favorable in spite of this "handicap," the success of the challenge would be less subject to question. It is recognized that the introduction of this sort of bias against the newer system is satisfactory as a study technique only if it cannot subsequently be said that it prevented an otherwise fair hearing for the new method. No difficulties of this sort arose in this study since in spite of the bias against it,the wireline option fared very well.

The general approach adopted for the development of construction and installation costs was one of building up a basic unit cost from detailed cost categories in the construction and installation of the individual repeater or terminal station. Each site was classified in one of 16 cost categories according to the degree of construction difficulty and facility development. Each site was assigned its appropriate cost as calculated for each of the 16 categories. The link cost was then taken as the sum of the included site costs. This method was adopted after an examination of the reported total link construction and installation costs as reported in the quarterly reports from regional headquarters showed that they were not detailed enough to allow a meaningful analysis of the cost differences. Further, other areas of costs such as maintenance, and data processing were not available on a basis comparable to the information in these quarterly regional reports. Therefore, for the sake of consistency and flexibility of application,

the decision was made to develop and use basic unit costs built up from relatively detailed cost accounts and facility inventory lists.

INFORMATION SOURCES

The primary source of data for this study, particularly in the case of the microwave system, was necessarily the FAA.

Lists of the radar sites defining the two operating configurations were furnished by the Agency along with data concerning the numbers and location of existing microwave sites. The Agency also provided considerable information and advice concerning highly technical considerations materially influencing the course of the analysis as well as cost data concerning specific areas when available.

The wireline data used in this analysis was obtained from a variety of sources. In large part, it represents the best judgment of the authors after discussing the nature of the equipment with the designers of the equipment of the previous generation, the manufacturers of this equipment, the personnel now working on research, development, manufacturing, installation, operation and maintenance of the relevant type equipment.

The transmission charges were obtained from a simplified version of the tariff filed with the FCC.

Considerable assistance was given, particularly in the area of wireline transmission and data processing, by the MITRE Corporation and Burroughs Corporation.

THE MICROWAVE SYSTEMS

With the exception of a few microwave links planned for commercial operation, the presently programmed remoting network is made up of FAA owned and operated microwave facilities. For purposes of this study it is assumed that all links included in the network herein designated the "Presently Programmed System" (Case I) are installed or their funding is irretrievably committed.

In keeping with the statement of work described in an earlier section of this analysis, the costs assignable to a second, hypothetical, all-microwave network (designed to

provide coverage down to 5,000' MSL or 3,000' above terrain - Case II) are also developed.

The underlying premise of this cost analysis as put forth in the work statement is that all costs already incurred are to be considered sunk. The effect of this assumption on the analysis of the presently programmed system is, as was previously stated, to make only the operations and maintenance cost pertinent to the cost comparison of the alternative transmission techniques. In Case II, however, amortization of the construction and installation costs of links not as yet constructed must be considered in addition to the operation and maintenance costs of these facilities. In both cases the procurement and installation costs of the requisite data processing equipment will be included.

SITING METHODOLOGY

In Case I the great majority of microwave repeater locations are already in operation or decisions as to their probable location have been made. Wherever this is the case, the actual locations were used in this analysis.

For links included in both Case I and Case II for which the actual siting recommendation had not been made as of this writing, projections were made as to the number and character of the required repeater sites.

The following rules governed the location of repeaters on these projected microwave links:

1. Length of hop shall not exceed 30 miles, and will generally be 27 to 28 miles.

2. The first repeater site of a link will be located approximately midway between the radar site and the ARTC location (wherever known, the most current ARTCC site was used).

3. The remaining site locations will be plotted in both directions from the midpoint. This and the previous rule are designed to produce hops at both ends of the link which are somewhat shorter than the average hop over the rest of the link, short terminal hops being characteristic of microwave links.

4. Consideration of obvious signal fade areas such as long over-water hops, links very close to coastlines, swampy areas, and desert conditions, shall result in the adoption of a somewhat shorter average hop length for these areas.

5. Paths projected through very mountainous or other extremely difficult terrain shall follow the most accessible routing (i.e., valleys, large rivers, passes, etc.) consistent with circuity considerations.

6. Trunking shall be used wherever practicable, with the limitation that three paths be the maximum permissible over one geographical path.

7. Wherever possible, repeaters of links now, or programmed to be, obsolete shall be utilized in projected paths.

8. Projected path intercept angles in trunking situations shall be arranged to avoid violation of transmission path separation criteria.

Application of these rules to the radar-center pairs now connected with RML equipment resulted in a variation of the calculated number from the actual number of repeaters of less than two percent.

SITE LOCATION CLASSIFICATION

For reasons already put forth in preceding sections of this report, it was considered expedient to classify repeater and radar sites according to some method which could be used in conjunction with the subsequent costing exercise. It was felt that the minimum number of categories consistent with the identification of the important cost variances should be adopted. More than one-half of the total cost of a repeater is incurred in construction and installation costs. Variations in these costs are mainly attributable to variations in labor, transportation, and land acquisition costs. These costs, in turn, may reasonably be considered functions of the location of the site. Thus, four categories of location were considered adequate for distinguishing between various types of repeater locations:

1. Easy - A site with available access and no extraordinary construction difficulties or labor costs.

2. Urban - A site described in much the same way as an "easy" site with the exception of a cost differential which may be attributed to a slightly higher site acquisition cost and wage scale.

3. Remote - A site which requires a considerably greater expenditure in providing access way and transportation costs. In addition,it can be expected that labor costs and the on-site cost of materials will be significantly greater at these sites.

4. Difficult - A site which is characterized in much the same way as a "remote" site and differs primarily in degree.

FACILITY CLASSIFICATION

There are also variations to be encountered in the physical facilities that exist at the various repeater sites. These variations obviously have a significant effect on the cost of the facility. While there may be a great number of minor differences in the equipment from one facility to the next, the following four categories of facilities were considered to account for the major cost variations attributable to disparities in equipment:

1. Building and Tower Required - This category describes a site which requires the construction of both a building and a tower. For both existing and proposed sites the assumption is that the facility will be capable of physically accommodating a dual path trunkline without extensive structual modification.

2. Building Only Required - This site requires the construction of a building, but not of a tower. It is implicit that the antenna can be mounted on the building roof or other adjacent structure and still maintain proper fresnel clearance.

3. Tower Only Required - This site has an existing building, but requires the construction of a tower.

4. No Building or Tower Required - This site has an existing building and tower that can accommodate a proposed additional path without significant structural modification.

DEVELOPMENT OF UNIT COSTS

In order that link costs would be most accurately reflected, a methodology based on building up standard basic unit costs for both terminal pairs and repeaters was adopted. This method provides obvious advantages through standardization of costing procedures and flexibility of modification to reflect differences in operating environments.

Development of Basic LMWR Costs

Through reference to copies of submitted abstracts of Bids and Awards (Form ACA 275 Rev. 3-15-41) and consultation with Agency personnel involved in related areas of effort, the costs in Table II were developed. The costs developed in this table apply to microwave repeater facilities, while those in Table III relate to terminal facilities.

TABLE II

DEVELOPMENT OF LMWR CONSTRUCTION AND INSTALLATION COST

Item	Urban	Easy	Remote	Difficult
Clearing and Grubbing	$ 500	$ 200	$ 500	$ 1,000
Site Preparation	400	200	400	600
Soil Sterilization	200	150	200	300
Surface Material	800	600	1,000	1,500
Fence	1,500	1,500	1,500	1,600
Gate	80	80	80	90
Guard Parts	160	120	160	200
Building	12,000	10,000	15,000	20,000
Install Engine Generator	500	400	700	1,000
Install Fuel Tank	200	150	300	400
Erect Tower	2,000	2,000	4,000	4,000
Install Grounding Systems	150	100	200	500
Additional Ground Rods	60	60	80	100
Access Road	0	0	5,000	10,000
Engine Generator	6,000	6,000	6,000	6,000
Tower[b]	4,000	5,000	5,000	3,000
Building Modification[a]	0	0	1,000	2,000
Miscellaneous Govt't. Items	3,000	3,000	4,000[c]	5,000[c]
Total	$31,550	$29,560	$45,120	$57,920

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a/ Buildings in remote and difficult sites are assumed to require modification to resist continued exposure to adverse conditions and infrequent inspections.

b/ This tower cost assumes a tower height of approximately 200 ft. for urban locations, 250 ft. for Easy and Remote locations, and 150 ft. for Difficult locations.

c/ These sites are often stocked with survival equipment and have limited personnel accommodations. Also some sites are equipped with non-standard accessories to protect the structure and equipment from unusual stresses.

Note: It is assumed that the procurement cost of individual items of Government furnished equipment will be the same regardless of where they are installed.

TABLE III

DEVELOPMENT OF LMWT CONSTRUCTION AND INSTALLATION COSTS

(Costs Shown Are For A Single Terminal and Not a Terminal Pair)

	Building and Tower Required	Building Only Required	Tower Only Required	No Building No Tower Required
Civil Engineering	$ 5,000	$ 3,000	$ 700	$ 700
Electrical Engineering	3,000	2,000	800	800
Building	10,000	10,000	0	0
Guard Ports for Fuel Tank	150	150	150	150
Install Engines Generator	400	400	0	0
Install Fuel Tank	150	150	0	0
Erect Tower	2,000	200	2,100a/	200
Install Guard System	100	100	150b/	100
Additional Guard Rods	60	60	60	60
Building Modification	0	0	2,000	2,150c/
Engine Generator	6,000	6,000	0	0
Tower	5,000	0	5,000	0
Total	$31,860	$22,060	$10,960	$4,160
Percent of Most Costly Category	100.0	69.2	34.4	13.1

a/ A slightly higher cost is indicated here to reflect the possibility that a tower erected at an established site may involve incremental costs which would be avoidable if the tower was erected at the time of the original site construction.

b/ Higher cost is indicated to reflect the possibility that a grounding system installed for a subsequently installed tower may be somewhat more costly than a similar system installed on an integrated basis for the entire facility.

c/ Since an additional antenna for this configuration will be mounted on the building or other established structure, a nominal cost of modifying this structure is reflected.

Development of Cost Matrices

Since both terminal and repeater sites have variations in costs due to variations in both inventory and location, the next step in the development of an applicable cost matrix is the gradation of the basic unit costs already developed according to the factor which was not considered in the basic cost computations. In other words, the basic repeater costs must be shaded to reflect the differences in equipment and the basic terminal costs must be shaded to reflect variations in location. The method that was used to accomplish this was to apply the percent variations of the "urban", "remote", and "difficult" repeater locations from the "easy" location cost to each of the four categories of basic terminal costs. Similarly the percent variation of the "building only required", "tower only required", and "no building-no tower required" facility costs from the "building and tower required" terminal facility basic cost was applied to each of the four categories of basic repeater construction costs. This process resulted in the cost matrices presented in Table IV and Table V.

TABLE IV

MATRIX OF LMWR (REPEATER) CONSTRUCTION AND INSTALLATION COSTS

	Urban	Easy	Remote	Difficult
Building and Tower Required	$31,550	$29,560	$45,120	$57,920
Building Only Required	21,833	20,456	31,223	40,081
Tower Only Required	10,853	10,169	13,801a/	16,484a/
No Building or Tower Required	4,133	3,872	5,256a/	6,278a/

a/ Percentages were applied to basic location costs less the cost assigned to construction of accessway on the premise that the inclusion of this cost would provide an unrealistically high base against which to apply the percentage due to the availability of access to the already existing facility, even though the two facilities may be merely adjacent rather than common.

TABLE V

MATRIX OF LMWT (TERMINAL) CONSTRUCTION AND INSTALLATION COSTS

	Urban	Easy	Remote[a/]	Difficult[a/]
Building and Tower Required	$33,995	$31,860	$43,234	$51,645
Building Only Required	24,994	22,060	30,421	40,017
Tower Only Required	10,949	10,960	13,185	14,303
No Building or Tower Required	4,551	4,160	4,776	6,273

Note: It will be noted that a shift in the relationship between ties occurs between the costs developed for the terminal and repeater facilities occurs between the "Urban" and "Remote" categories. This reflects the contention that a terminal facility can never become as costly as a repeater facility at more difficult sites because of the fact that it is virtually always located on a site prepared for the radar facility. In the easier installations the terminal facility (of similar construction characteristics) is generally more expensive due to the fact that it is more elaborate physically and electronically.

a/ See Note above. Thus the following percentage adjustments apply:

Site Location Classification	Cost	Percent Adjustment
E	$29,560	100.0
U	31,550	106.7
R	40,120	135.7
D	57,920	162.1

Interpretation of Unit Costs

The basic repeater construction and installation cost categories were built up on the basis of variations in costs of essentially similar installations. The cost gradations effected by modifying these basic costs by factors designed to reflect variations in cost of dissimilar installations (from the standpoint of construction and installation) require some further description of the facility to which they apply.

The basic repeater facility is considered to include both a building and a tower. This type of facility for each site location classification will be the most costly.

The repeater facility which requires a building only is located in such a position on the link that the proper fresnel clearance can be maintained without the use of a tower separate from the building. This category could apply to either an initial installation or the addition of a subsequent path which required an extensive modification of the existing building structure, but not requiring the erection of a second tower.

The tower-only cost category may be applied to initial installation where an adequate structure already exists for housing the required electronic equipment. It may also be applied to trunking situations where a third path is to be established along an already dualized route and/or when the path intercept angle is not within proper tolerances to preclude interference.

The situation where a facility requires no tower and no building is generally encountered in the establishment of the second path on an existing single path route.

Each of the above cost categories has been designed to include all attributable costs contingent with the extent of the particular facility.

Development of Maintenance Costs

Maintenance costs were developed under much the same philosophy as the construction and installation costs, i.e., that these costs vary according to some factor. Since the Agency maintains records concerning local maintenance costs, the development of these costs for use in this study was largely based on maintenance estimates made by the regions

for specific repeater and terminal sites or for entire links. Again for purposes of standardizing the approach and maintaining flexibility in application, these cost levels were classified in four location categories comparable to those used for the basic repeater construction and installation costs - easy, urban, remote, difficult. Table VI presents the operation and maintenance costs adopted for this study.

In general, the classification of sites for purposes of assigning construction and installation costs governed the maintenance cost assigned. Variations in this rule occurred only where obvious disparities in the expected construction and maintenance environments exist. For instance, in coastal areas, fading problems are often encountered necessitating a relatively high maintenance cost cost while there may be little or no unusual construction problems. In this case separate classifications for construction and for maintenance were employed. It is recognized that a reasonable argument may be made that there are disparities in the maintenance attributable to whether or not a facility requires a separate building and/or tower. For purposes of this study such a differential was not considered significant.

TABLE VI

ANNUAL OPERATION AND MAINTENANCE COSTS
FOR MICROWAVE FACILITIES

	Maintenance	Spares	Total
Repeaters			
Easy	$12,000	$2,000	$14,000
Urban	13,000	2,000	15,000
Remote	16,000	2,500	18,500
Difficult	18,000	2,500	20,500
Terminals			
Easy	$14,000	$3,000	$17,000
Urban	15,000	3,000	18,000
Remote	17,000	3,500	20,500
Difficult	25,000	3,500	28,500

Development of Electronic Equipment Costs

Without prior knowledge of the size of the order or other special variables concerning the procurement of RML electronic equipment, the approximate per unit amount of the last sizeable purchase of this type of equipment was adopted as reasonable. Procurement costs for this equipment were determined not to vary from site to site due to a policy of centralized purchasing of large lots. It is recognized that there probably exists some differential in the installation costs of the electronic equipment of the various sites, however, this differential is considered to be part of the differential built into the overall construction and installation cost. These assumptions apply to both the equipment required at LMWR and LMWT sites. The costs adopted for use in this study are $24,000 and $130,000 (including purchase and installation) for a LMWR and a terminal pair respectively.

In the case of the "Beacon-Only" option, it is recognized that there would be a difference in the procurement costs of RML electronic equipments designed for transmission of beacon data only and those costs associated with equipments required to transmit raw radar data in addition to beacon data. However, the fact that the purchase of all the required RML equipment (all having dual capability) in the presently programmed all-microwave configuration is considered sunk precludes the necessity for compensating for this differential in Case I. In Case II, which is presented as a "least cost" exercise, it is obvious that there will be sufficient surplus RML equipment to equip all remaining new sites, therefore,these equipments are included in the calculation at zero cost.

Maintenance and operation costs for the "Beacon-Only" option are considered to vary from the "Raw Radar plus Beacon" option by $6,000 per terminal pair. No appreciable difference in the operation and maintenance costs of the electronic equipment at repeater sites could be determined.

Development of Data Processing Costs[2/]

A specific condition of the work statement was that all remoting networks should include facilities for analog to digital processing of the radar signal.

2/ See Note to "Abstract".

The data flow for the all-microwave network is an analog transmission from the radar site via the broad band microwave link to the ARTCC where it is converted into digital form by special purpose computers similar in many respects to military AN/FST-2B's.

After considerable analysis (discussed more fully in the subsequent section on the development of wireline costs) it was determined that the installation of a new FAA solid state modernized digital computer (which we shall call an "FAA T-2B") was the most economical system in every case, including sites now equipped with Air Force owned AN/FST-2s in its various versions and those sites which now have no radar data processing equipment. The cost for a simplex FAA T-2B was determined to approximate $250,000 including fabrication and installation. An annual maintenance cost of $125,000 was assigned to complexes of one to five simplex machines. An incremental annual maintenance cost of $25,000 per machine was used for complexes of more than five simplex processors.

For all-microwave remoting networks one simplex processor was assigned to each link with one spare processor required for complexes of up to four simplex on-line processors. Two spares were allocated to complexes of five to ten on-line simplex processors inclusive.

Following the above system and cost description, Table VII presents the data processing cost according to the number of links assigned per ARTCC.

TABLE VII

UNIT COSTS FOR DATA PROCESSING CAPABILITY
(ANNUAL)

No. of Micro-wave Links	Annual Amortization[b] of FAA T-2B Construction and Installation Cost		Annual Operation and Maintenance Costs		Total of Amortization Plus Operation and Maintenance Cost	
	Raw Radar Plus Beacon	Beacon Only	Raw Radar Plus Beacon	Beacon Only	Raw Radar Plus Beacon	Beacon Only
1	$50,000	$40,000	$125,000	$120,000	$175,000	$160,000
2	37,500	30,000	62,500	60,000	100,000	90,000
3	33,333	26,667	41,667	40,000	75,000	66,667
4	31,250	25,000	31,250	30,000	62,500	55,000
5	35,000	28,000	35,000	33,600	70,000	61,600
6	33,333	26,667	33,333	32,000	66,667	58,667
7	32,143	25,714	32,143	30,857	62,286	56,571
8	31,250	25,000	31,250	27,500	62,500	52,500
9	30,556	24,444	30,556	26,667	61,112	51,111
10	30,000	24,000	25,000	24,000	55,000[a]	48,000[a]

a/ Assumes two complete teams at $125,000 and $120,000 per year (Raw Radar plus Beacon and Beacon Only respectively) can maintain a maximum of 12 simplex processors.

b/ Assumes 10 Year Service Life.

APPLICATION OF UNIT COSTS

In order that a meaningful cost differentiation may be obtained on a link-by-link basis, each link was described and applicable costs assigned on a site-by-site basis for remoting configurations. Table IX is a list of the radars considered in this analysis, the number of their respective repeaters and their associated costs.

The method used in the plot and classification of sites has been described in a preceding section. The inventory of sites and the applicable link lengths may be found in Appendix A. Table VIII summarizes the systemwide costs of microwave remoting:

TABLE VIII

	Presently Programmed System		Hypothetical System	
	Radar Beacon	Beacon Only	Radar Beacon	Beacon Only
Systemwide Cost of Microwave Remoting (In Millions)	$18.5	$17.4	$24.9	$23.3

TABLE IX

ANNUAL COSTS APPLICABLE TO ALL-MICROWAVE SYSTEMS

ARTCC Radar Site	No. of Repeater Sites	Annual Microwave Costs			
		Case I		Case II	
		Radar Beacon	Beacon Only	Radar Beacon	Beacon Only
Boston					
Bucks Harbor	9	$255,000	$240,667	$290,961	$277,461
Boston	2	166,000	151,667	135,905	122,405
Saratoga Springs	4	195,500	181,167	170,431	156,931
Watertown[b]	8	-	-	230,663	217,163
		616,500	573,501	827,960	773,960
New York					
Benton[a]	6	200,000	185,667	-	-
Montauk	4	159,500	145,167	159,000	144,667
Palermo	7	211,000	196,667	210,000	196,667
Pottersville[b]	9	-	-	257,593	243,260
		570,500	527,501	627,593	584,594
Washington					
Cherry Point[b]	10	-	-	265,637	251,637
Benson	10	242,000	228,500	246,167	232,167
Cape Charles	7	201,000	187,500	205,167	191,167
Roanoke	6	181,500	168,000	186,167	172,167
Kessel[b]	3	-	-	160,409	146,409
Washington	1	112,500	99,000	116,667	102,667
		737,000	683,000	1,180,214	1,096,214

ARTCC Radar Site	No. of Repeater Sites	Annual Microwave Costs			
		Case I		Case II	
		Radar Beacon	Beacon Only	Radar Beacon	Beacon Only
Jacksonville					
Charleston	8	$230,500	$216,100	$227,167	$213,167
Valdosta	3	142,000	127,600	138,667	124,667
Jacksonville	1	121,000	106,600	117,667	103,667
Beaufort[b]	5	-	-	188,742	174,742
Dauphin Island	16	355,000	340,600	351,667	337,667
Tyndall AFB[b]	10	245,000	230,600	241,667	227,667
		1,093,500	1,021,500	1,265,577	1,181,577
Miami					
Patrick AFB	7	234,000	218,000	209,000	194,667
Tampa	9	264,000	248,000	239,000	224,667
Cross City[b]	12	-	-	310,058	295,725
		498,000	466,000	758,058	715,059
Cleveland					
Dansville[a]	9	246,000	231,667	-	-
Philipsburg[b]	8	-	-	200,495	186,995
Detroit	4	168,000	153,667	155,500	142,000
Pittsburgh	5	183,000	168,667	170,500	157,000
Lockport [b]	8	-	-	221,670	208,170
		597,000	554,001	748,165	694,165
Indianapolis					
New Harmony[b]	4	-	-	174,309	160,309
Lynch	10	279,500	263,500	246,167	232,167
London	5	207,000	191,000	173,667	159,667
Huntington[b]	9	-	-	239,953	225,953
Lexington[b]	5	-	-	184,664	170,664
Rockville[b]	1	-	-	119,719	105,719
		486,500	454,500	1,138,479	1,054,479

ARTCC Radar Site	No. of Repeater Sites	Annual Microwave Costs			
		Case I		Case II	
		Radar Beacon	Beacon Only	Radar Beacon	Beacon Only
Atlanta					
Atlanta	3	$139,500	$126,000	$141,286	$127,571
Montgomery	5	167,500	154,000	169,286	155,571
Lynch	13	288,500	275,000	290,286	276,571
McCormick[b]	5	-	-	175,467	161,752
Charlotte	8	210,500	197,000	212,286	198,571
Birmingham[b]	6	-	-	195,410	181,695
Crossville[b]	9	-	-	261,113	247,398
		806,000	752,000	1,445,134	1,349,129
Minneapolis					
Houghton	9	283,500	267,500	258,400	244,167
Minneapolis	1	151,000	135,000	126,000	111,667
DeSoto[b]	4	-	-	178,920	164,587
		434,500	402,500	563,420	520,421
Chicago					
Chicago	1	121,000	106,600	115,286	101,571
Traverse City	12	283,000	268,600	277,286	263,571
La Grange	6	191,000	176,600	185,286	171,571
Horicon	4	162,000	147,600	156,286	142,571
West Branch	6	194,500	180,100	188,786	175,071
Hanna City[b]	4	-	-	167,335	153,620
Afton, Ia.[b]	12	-	-	289,693	275,978
		951,500	879,500	379,958	1,283,953
Kansas City					
St. Louis	9	225,500	212,000	227,286	213,571
Hutchinson	7	195,500	182,000	197,286	183,571
Garden City	13	279,500	266,000	281,286	267,571
Omaha	7	195,500	182,000	197,286	183,571
Kirksville[b]	4	-	-	166,663	152,948
Fairfield[b]	3	-	-	150,279	136,564
Strange[b]	4	-	-	168,206	154,491
		896,000	842,000	388,292	1,292,287

ARTCC Radar Site	No. of Repeater Sites	Annual Microwave Costs			
		Case I		Case II	
		Radar Beacon	Beacon Only	Radar Beacon	Beacon Only
Memphis					
Crystal Springs	9	$262,000	$246,000	$232,000	$217,600
Nashville	7	235,000	219,000	205,000	190,600
Greenville[b]	4	-	-	162,239	147,839
Walnut Ridge[b]	3	-	-	166,742	152,342
Little Rock[b]	4	-	-	180,975	166,575
		497,000	465,000	946,956	874,956
Fort Worth					
Odessa	11	264,000	249,667	246,500	233,000
Oklahoma City	6	196,000	181,667	178,500	165,000
Texarkana	7	208,000	193,667	190,500	177,000
Perrin AFB[b]	1	-	-	110,552	97,502
Palestine[b]	4	-	-	161,420	147,920
Elk City[b]	8	-	-	231,188	217,688
Seymour[b]	4	-	-	161,420	147,920
Sweetwater[b]	8	-	-	209,718	201,655
Peyote[b]	13	-	-	291,873	278,373
Strang[b]	9	-	-	238,252	224,752
		668,000	625,001	2,019,923	1,884,923
Houston					
Crowley[b]	6	-	-	199,492	185,992
New Orleans	13	330,000	315,667	317,500	304,000
Alexandria	9	260,500	246,167	248,000	234,500
San Antonio	8	223,000	208,667	210,500	197,000
		813,500	770,501	975,492	921,492

ARTCC Radar Site	No. of Repeater Sites	Annual Microwave Costs			
		Case I		Case II	
		Radar Beacon	Beacon Only	Radar Beacon	Beacon Only
Denver					
Denver	1	$117,666	$103,666	$117,666	$103,666
Gallup	18	419,666	405,666	419,666	405,666
Grand Junction	9	281,666	267,166	281,666	267,166
Trinidad	7	216,666	202,666	216,666	202,666
North Platte	9	228,666	214,666	228,666	214,666
Wheatland	7	225,666	211,666	225,666	211,666
		1,489,496	1,405,496	489,496	1,405,496
Albuquerque					
Mesa Rica	4	182,500	168,100	176,786	163,071
Amarillo	10	267,500	253,100	261,786	248,071
Silver City	12	338,500	324,100	332,786	319,071
El Paso	10	286,500	272,100	280,786	267,071
Phoenix	20	474,000	459,600	468,286	454,571
Winslow[b]	7	-	-	240,964	227,249
Tucson[b]	17	-	-	340,286[c]	326,571[c]
		1,549,000	1,477,000	2,101,680	2,005,675
Salt Lake City					
Battle Mountain	13	332,166	318,166	332,166	318,166
Boise	13	345,666	331,666	345,666	331,666
Rock Springs	6	228,166	214,166	228,166	214,166
Lovell	12	345,166	331,166	345,166	331,166
Ashton	11	305,166	291,166	305,166	291,166
Cedar City	10	295,666	281,666	295,666	281,666
		1,851,996	1,767,996	1,851,996	1,767,996

ARTCC Radar Site	No. of Repeater Sites	Annual Microwave Costs			
		Case I		Case II	
		Radar Beacon	Beacon Only	Radar Beacon	Beacon Only
Los Angeles					
Las Vegas	8	$265,666	$251,666	$265,666	$251,666
Boron	2	147,666	133,666	147,666	133,666
Paso Robles	6	194,666	180,666	194,666	180,666
Los Angeles	2	132,666	118,666	132,666	118,666
El Centro	8	258,166	244,166	258,166	244,166
Cedar City	17	434,166	420,166	434,166	420,166
		1,432,996	1,348,996	1,432,996	1,348,996
Oakland					
Paso Robles	6	192,500	178,100	189,176	175,176
Sacramento	4	165,000	150,600	161,667	147,667
Red Bluff	7	214,000	199,600	210,667	196,667
Fallon	11	309,000	294,600	305,667	291,667
Tonopah	15	381,000	366,600	377,667	363,667
Fortuna[b/]	10	-	-	269,457	255,457
		1,261,500	1,189,500	1,514,301	1,430,301
Seattle					
Salem	8	227,000	212,600	227,000	212,600
Klamath Falls	16	358,000	343,600	358,000	343,600
Spokane	8	264,500	250,100	264,500	250,100
Condon	8	264,500	250,100	264,500	250,100
Seattle	2	121,000	106,600	121,000	106,600
		1,235,000	1,163,000	1,235,000	1,163,000
Grand Total		18,485,488	17,368,493	24,890,690	23,348,673

a/ Appear only in Case I. (Presently Programmed network)

b/ Appear only in Case II. (Hypothetical network to provide coverage to 5000'MSL or 3000' above terrain whichever is higher)

c/ The microwave cost indicated for Tucson was based on the somewhat unrealistic assumption that it could be trunked at only incremental cost on the Phoenix-Albuquerque path. This assumption violates one of the basic rules of this analysis in that it creates a four-path link at minimum incremental expense. However, a major revision in the path system related to the Albuquerque ARTCC was not considered within the scope of this report. Therefore, the cost indicated for Tucson-Albuquerque microwave link must be viewed as considerably understated according to the assumptions of this report.

Note: The following eight presently programmed radar were not included in this analysis because they are either remoted via coaxial cable or their status in the nationwide remoting network could not be firmly established:

Cleveland	Fayetteville
Fort Worth	Salt Lake City
Tucumcari	Los Angeles (ASR)
Little Rock (Inc. Case II)	Burlington

THE WIRELINE SYSTEM

GENERAL DISCUSSION

The alternative to microwave transmission of essentially unprocessed radar and semi-processed beacon data with subsequent processing at the ARTCC is that of processing at the radar site and transmitting the resulting data via wireline. See the previous report for further discussions of this method.3/

NETWORK DEFINITIONS

The network of Radars and ARTCC's between which transmissions of radar data is to take place is just the same in this case as in the microwave cases preceding.

THE VARIABLES IN WIRELINE COSTING

The costs of remoting radar data via wireline may be divided into two categories: one, those costs associated with the actual transmission of the data and the other, those costs associated with the conversion of the radar and beacon video into digital form suitable for the wireline system.

TRANSMISSION CHARGES

It is estimated that three-voice grade circuits are required to transmit the data from one radar site.4/ This number includes a spare, normally used as an order wire, but equipped for instant employment as a spare circuit. As previously shown,5/ the annual charges for such lines are, for three lines taken together, $540.00 for termination charges, $3,840.00 for duplexed Dataphones and line charges as indicated in Table X:

3/ Techniques and Costs of Radar Remoting, July 1962, Systems Analysis and Research Corporation.

4/ Ibid.

5/ Ibid.

TABLE X

Wireline Transmission Charges

Distance	Rate
0-100 miles	$135/mile
101-300 miles	+ 87.75/mile
301-700 miles	+ 74.25/mile
701-1500 miles	+ 60.75/mile

TABLE XI

TOTAL WIRELINE CHARGES[a/]

Distance in Miles	Annual Charge In Dollars	Distance in Miles	Annual Charge In Dollars
0	$ 4,380.00	250	$31,042.50
10	5,730.00	260	31,920.00
20	7,080.00	270	32,797.50
30	8,430.00	280	33,675.00
40	9,780.00	290	34,552.50
50	11,130.00	300	35,430.00
60	12,480.00	310	36,172.50
70	13,830.00	320	36,915.00
80	15,180.00	330	37,657.50
90	16,530.00	340	38,400.00
100	17,880.00	350	39,142.50
110	18,757.50	360	39,885.00
120	19,635.00	370	40,627.50
130	20,512.50	380	41,370.00
140	21,390.00	390	42,112.50
150	22,267.50	400	42,855.00
160	23,145.00	410	43,597.50
170	24,022.50	420	44,340.00
180	24,900.00	430	45,082.50
190	25,777.50	440	45,825.00
200	26,655.00	450	46,567.50
210	27,532.50	460	47,310.00
220	28,410.00	470	48,052.50
230	29,287.50		
240	30,165.00		

a/ Including termination, Dataphones (duplexed) and Line charges for a three circuit requirement.

For this study distances have been measured from maps.[6/] The net result of these various charges can be expressed in tabular form as in Table XI on the preceding page.

DATA CONVERSION COST

The Data Processor

Data conversion is assumed done by means of a digital computer resembling, in many respects, the Air Force AN/FST-2. It will be called, for lack of bettern terminology, an "FAA, modernized, solid state T-2B" or, for short, FAA T-2B. The FAA T-2B may be approximated, however, by means of extensive modifications of existing Air Force AN/FST-2's. A so-called "mod kit" (modification kit) and its installation are needed. It is assumed that thus modified AN/FST-2 will meet Air Force data output requirements just as the FAA T-2B will. Inquiry within the FAA, and among outside manufacturers, agencies and laboratories yielded the cost estimates in Table XII for the data processor for both radar and beacon data (for beacon only, see paragraph below entitled "BEACON AND RADAR OR BEACON ONLY SYSTEM").

6/ Distances are calculated for tariff purposes according to a method which divides the country into small "cells" with the distance from any point in a particular cell to any point in another particular cell being considered the same. This permits the calculation of all cell-to-cell distances and the construction of a handbook (table) which permits one to look up the "distance" from any point to any point. This method was checked against the map measuring method used and found to agree very closely.

TABLE XII

COSTS FOR VARIOUS DUPLEXED DATA PROCESSORS

(Radar plus Beacon)

Type of Installation	Initial Cost to FAA[a/]	Annual Operation and Maintenance[b/]
AN/FST-2 alone	0[c/]	$150,000
AN/FST-2 modified with mod kit	$250,000	169,000
FAA T-2B installed with AN/FST-2	500,000	175,000
FAA T-2B instead of AN/FST-2	500,000	125,000

a/ "Turnkey" cost including construction, installation, etc. All costs shown are for added cost to FAA only and do not include cost of basic AN/FST-2 if present. See footnote c.

b/ Based on contract maintenance costs for comparability of data. Thus it is not implied that the Air Force spends $150,000 to maintain their AN/FST-2's themselves. They may spend more or less.

c/ Already sunk by Air Force. This line is given only to show AN/FST-2 maintenance for later use, since the AN/FST-2 alone is not capable of yielding FAA required data output.

Thus it can be seen that a number of possibilities exist and that one variable to the costing equation is the presence or absence of an existing Air Force AN/FST-2 at the site in question.

NETTING

Netting, the practice of tieing a given radar site to more than one ARTCC, is another important factor in radar remoting costing if, as is the case in this report, the costs are developed on a link basis rather than a site basis. Clearly, netting reduces the average link cost since those costs which are fixed per site are shared by all links radiating from that site. For example, if a radar is netted to two centers, each of the two links need be charged with but

half of the processor costs for that site. Relatively little netting is contemplated by the FAA, but it is clear that when netting is done, the per-link costs are substantially lowered for the wireline case.

ALLOCATION OF COSTS AMONG JOINT USERS

At some use sites the Air Force, the former "owner", had no requirement for remoting the radar, will have no future equirement for remoting the radar, and thus has no interest in the data processor output. Under these circumstances, anything the FAA installs, the FAA must pay for in full.

If, however, the Air Force had an AN/FST-2, it is assumed it will want processed radar data in the future. Any of the four alternatives in the foregoing paragraph entitled "DATA CONVERSION COST" yield the Air Force its data. Any except the first (AN/FST-2 only) yield the FAA theirs. Therefore, any one but the first may be chosen for joint use sites. The question immediately arises, however, of who shall pay for what. Various assumptions were made for the purposes of this study which may be briefly summarized as follows, arranged in order of decreasing attractiveness to the FAA.

1. The Air Force pays what it is now paying. FAA pays any additional costs. The Air Force, since it has sunk the cost of one AN/FST-2, will not pay any initial costs of the FAA T-2B, except that if FAA spends $500,000 for the FAA T-2B to get the operation and maintenance (O&M) costs down to $125,000 the Air Force will contribute the $150,000 less $125,000 or $25,000 from their O&M account toward the FAA's amortization of the FAA T-2B.

2. Same as above except that is assumed that the Air Force will not pay the jointly saved O&M money toward the amortization of FAA T-2B.

3. Same as above for initial costs. FAA and Air Force share O&M on 50-50 basis if they use the same machine (alternative 2 and 4) except that in the case of the FAA T-2B alone, the Air Force will pay FAA half the saving it realized through FAA's expenditure of $500,000 for the FAA T-2B rather than the $250,000 for the mod kit. The result is that FAA's O&M costs are $84,500 for the modified Air Force AN/FST-2 ($\frac{\$169,000}{2}$ with Air Force paying an equal

amount) and $51,000 for an FAA T-2B (Air Force pays $\frac{\$125,000}{2}$ or $62,500 plus half of $84,000 - $62,500 or $22,000 for a total Air Force contribution of $62,500 + $11,000 or $73,500. This from the $125,000 cost leaves the FAA with $51,500 to pay.)

4. Same as above for initial costs. FAA pays all O&M costs for any Air Force processor equipment it uses in whole or in part, i.e., FAA pays $169,000 O&M for a modified AN/FST-2, $125,000 for (O&M) FAA T-2B installed beside the Air Force T-2 (the latter not used by the FAA) and $125,000 O&M for an FAA T-2B installed instead of an Air Force AN/FST-2, but used by both.

The actual nature of the cost sharing which might take place would, of course, be the result of negotiations between the FAA and the Air Force.

For this study it was unwise to assume conditions too favorable to the FAA; conditions which might never materialize. For this reason it was decided that only assumptions 3 and 4 above, concerning costs sharing, would be used. Furthermore, consultation with the FAA indicated that assumption 4 was the most critical one for which it was felt that results would be essential. Therefore, the problem was seen through in its entirety only under this assumption. Data for assumption 3 is given in Table XV,but these data have not been carried through the system cost minimization process. Nevertheless, the data from Table XV may be readily compared with the data for assumption 4 given in the following section, titled "BEACON AND RADAR OR BEACON ONLY SYSTEM," to see the effect of changing this assumption.

BEACON AND RADAR OR BEACON ONLY SYSTEM

The last important variable on the wireline cost side is the question of whether the FAA requirement will be one for both beacon and primary radar data or for beacon data alone. This is important not because remoting only beacon data would necessarily be a good deal cheaper (it would not), but because to reverse a decision to provide beacon only might be rather expensive. Furthermore, in those cases in which the Air Force now has an AN/FST-2 installed, no change can be contemplated which would eliminate the provision of processed primary radar since that is an obvious Air Force requirement. Thus the "beacon only" case reverts to the "beacon and primary radar" case at all Air Force sites with

AN/FST-2's, i.e., the FAA T-2B is a full beacon plus radar machine when used alone, as is the mod kit, for such sites. At FAA sites or Air Force sites without AN/FST-2's a beacon-only FAA T-2B could be installed. Costs for beacon-only cases are assumed to be the same as for beacon-plus-primary-radar cases, though it might be possible to cut the costs by one-third under certain conditions of low traffic densities. Costs for data conversion for beacon only are indicated in Table XIII.

TABLE XIII

COSTS FOR VARIOUS DUPLEXED DATA PROCESSORS PROVIDING BEACON-ONLY DATA TO THE FAA

Type of Installation	Initial Cost to FAA[a/]	Annual Operation and Maintenance[b/]
AN/FST-2 alone	0[c/]	$150,000
AN/FST-2 modified with mod kit	$200,000	169,000[d/]
FAA T-2B installed with AN/FST-2	400,000	175,000[d/]
FAA T-2B instead of AN/FST-2	500,000	125,000

a/ "Turnkey" cost including construction, installation, etc. All costs shown are for added cost to FAA only and do not include cost of basic AN/FST-2 if present.

b/ Based on contract maintenance costs for comparability of data. Thus it is not implied that the Air Force spends $150,000 to maintain their AN/FST-2's themselves. They may spend more or less.

c/ Already sunk by Air Force. This line is given only to show AN/FST-2 maintenance for later use, since AN/FST-2 alone is not capable of yielding FAA required data output.

d/ Slight reductions in maintenance costs might be imagined, but these would in any case be so small as to be in the noise for the purposes of this study.

THE WIRELINE COST MATRIX

From the discussion above it is clear that to determine the cost of transmission over a given link for a year, one must know the following:

1. Whether the radar site has an AN/FST-2 or not. For our purposes here, sites may be classified as Air Force with AN/FST-2 (AFT2), Air Force without AN/FST-2 (AF) or FAA (FAA).

2. Whether the radar is netted or not and if so, to how many sites.

3. The cost sharing assumption to be used. In the case of this report, the last, i.e., the most unfavorable one from the FAA standpoint is used, as was mentioned previously.

4. Whether the system is to transmit both beacon and primary radar or beacon only.

5. Amortization period for the equipment. Ten years is assumed here just as in the previous study.

6. The site-to-center distance.

It will be noted that the annual transmission charge depends only on the last of these, while the annual data conversion cost depends only on the first five and not at all on the last.

The total annual cost under any circumstances is then:

(a) the transmission cost from Table I plus

(b) the data conversion cost.

APPLICATION OF COSTS DEVELOPED TO GIVEN COSTS

The minimum costs for the various possible combinations of circumstances, developed in the previous section, have been applied to all the links in the two cases under examination in this study. Table XIV presents the costs under the assumptions that the FAA pays the entire wireline cost. Table XV assumes that the FAA shares equally with the AF the data processing costs. Table XVI presents the costs of an all wireline nationwide network.

TABLE XIV

DATA CONVERSION COSTS[a/]
(in dollars)

(No cost sharing assumed: FAA pays all cost of equipment it uses.)

OPTION	Radar and Beacon Site Type		Beacon Only Site Type	
	AFT2	AF or FAA	AFT2	AF or FAA
Mod Kit				
Amortization	25,000	N/A	25,000	N/A
Op. & Maint.	169,000	N/A	169,000	N/A
Total	194,000	N/A	194,000	N/A
FAA T-2B + AN/FST-2				
Amortization	50,000	N/A	40,000	N/A
Op. & Maint.	125,000	N/A	120,000	N/A
Total	175,000[b/]	N/A	160,000[b/]	N/A
FAA T-2B Alone				
Amortization	50,000	50,000	50,000	40,000
Op. & Maint.	125,000	125,000	125,000	120,000
Total	175,000[b/]	175,000[b/]	175,000	160,000[b/]

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a/ All costs are for unnetted radar. If sites netted divide by number of centers.

b/ Minimum cost options.

TABLE XV

DATA CONVERSION COST[a/]
(in dollars)

(50-50 AF/FAA O&M Cost Sharing)

OPTION	Radar and Beacon Site Type		Beacon Only Site Type	
	AFT2	AF or FAA	AFT2	AF or FAA
Mod Kit				
Amortization	25,000	N/A	25,000	N/A
Op. & Maint.	84,500	N/A	84,500	N/A
Total	109,500	N/A	109,500	N/A
FAA T-2B & AN/FST-2				
Amortization	50,000	N/A	50,000	N/A
Op. & Maint.	87,500	N/A	87,500	N/A
Total	137,500	N/A	137,500	N/A
FAA T-2B Alone				
Amortization	50,000	50,000	50,000	40,000
Op. & Maint.	51,500	125,000	51,500	120,000
Total	101,500[b/]	175,000[b/]	101,500[b/]	160,000[b/]

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a/ All costs are for unnetted radar. If site is netted, divide by the number of centers to which radar is remoted to get data conversion cost per link.

b/ Minimum cost options.

TABLE XVI

TOTAL LINK COSTS APPLICABLE TO ALL-WIRELINE SYSTEM

Radar Facility Classification	ARTCC Radar Site	Straight-Line Mileage	Annual Wireline System Cost: FAA Pays All Costs — Radar Plus Beacon	FAA Pays All Costs — Beacon Only	FAA Pays One-Half of Data Processing Costs[c] — Radar Plus Beacon	FAA Pays One-Half of Data Processing Costs[c] — Beacon Only
	Boston					
AFT2	Bucks Harbor	240	$265,165	$190,165	$131,665	$139,665
AFT2	Boston	40	184,780	169,780	111,280	119,280
AFT2	Saratoga Springs	130	195,512	180,512	122,012	130,012
AFT2	Watertown[b]	280	208,675	193,675	135,175	143,175
			794,132	734,132	500,132	532,132
	New York					
AFT2	Benton[a]	170	199,022	184,022	124,522	133,522
AFT2	Montauk	60	187,480	172,480	113,980	121,980
AFT2	Palermo	130	195,512	180,512	122,012	130,012
FAA	Pottersville[b]	200	201,655	186,655	201,655	186,655
			584,647	539,647	437,647	438,647
	Washington					
AFT2	Cherry Point[b]	280	208,675	193,675	135,175	143,175
FAA	Benson	250	206,042	191,042	206,042	191,042
AFT2	Cape Charles	160	198,145	183,145	124,645	132,645
AFT2	Roanoke	150	159,268	182,268	123,768	131,768
FAA	Kessel[b]	110	193,758	178,758	193,758	178,758
FAA	Washington	40	184,780	169,780	184,780	121,980
			1,188,668	1,098,668	968,168	899,368

Radar Facility Classification	ARTCC Radar Site	Straight-Line Mileage	Annual Wireline System Cost: FAA Pays All Costs — Radar Plus Beacon	FAA Pays All Costs — Beacon Only	FAA Pays One-Half Data Processing Costs[c/] — Radar Plus Beacon	FAA Pays One-Half Data Processing Costs[c/] — Beacon Only
	Jacksonville					
AFT2	Charleston	190	$200,778	$185,778	$127,278	$135,278
AF	Valdosta	80	190,180	175,180	190,180	175,180
AFT2	Jacksonville	30	183,430	168,430	109,930	118,930
Navy	ufort[b/]	160	198,145	183,145	198,145	183,145
AFT2	uphin Island	390	217,111	202,112	143,611	151,611
AFT2	Tyndall AFB	220	203,410	188,410	129,910	137,910
			1,193,054	1,103,055	899,054	902,054
	Miami					
AFT2	Patrict AFB	170	199,022	184,022	125,522	133,522
AFT2	Tampa	200	201,655	186,655	128,155	136,155
AFT2	Cross City[b/]	330	212,658	197,658	139,158	147,158
			613,325	568,335	392,835	416,835
	Cleveland					
FAA	Dansville[a/]	190	200,778	185,778	200,778	185,778
FAA	Phillipsburg[b/]	220	203,410	188,410	203,410	188,410
FAA	Detroit	90	191,530	176,530	191,530	176,530
AFT2	Pittsburgh	130	195,512	180,512	122,012	130,012
AFT2	Lockport[b/]	220	203,410	188,410	129,910	137,910
			793,862	733,862	646,862	818,640

Radar Facility Classification	ARTCC Radar Site	Straight-Line Mileage	Annual Wireline System Cost: FAA Pays All Costs — Radar Plus Beacon	FAA Pays All Costs — Beacon Only	FAA Pays One-Half of Data Processing Costs[c] — Radar Plus Beacon	FAA Pays One-Half of Data Processing Costs[c] — Beacon Only
	Indianapolis					
FAA	New Harmony[b]	150	$197,268	$182,268	197,268	182,268
FAA	Lynch	270	207,798	192,798	207,798	192,798
FAA	London	150	197,268	182,268	197,268	182,268
FAA	Huntington[b]	210	202,532	187,532	202,532	187,532
FAA	Lexington[b]	120	194,635	179,635	194,635	179,635
AF	Rockville[b]	80	190,180	175,180	190,180	175,180
			1,189,681	1,099,681	1,189,673	1,099,681
	Atlanta					
AFT2	Atlanta	40	184,780	169,780	111,280	119,280
FAA	Montgomery	140	196,390	181,390	196,290	181,390
FAA	Lynch	260	206,920	191,920	206,920	191,920
FAA	McCormick[b]	130	195,512	180,512	195,512	180,512
FAA	Charlotte	230	204,288	189,288	204,288	189,288
FAA	Birmingham[b]	140	196,390	181,390	196,390	181,390
FAA	Crossville[b]	200	201,655	186,655	201,655	186,655
			1,385,935	1,280,935	1,312,435	1,230,435
	Minneapolis					
AFT2	Houghton	260	206,920	191,920	133,420	141,420
FAA	Minneapolis	30	183,430	168,430	183,430	168,430
FAA	DeSoto[b]	140	196,390	181,390	196,390	181,390
			586,740	541,740	513,240	491,240

Radar Facility Classification	ARTCC Radar Site	Straight-Line Mileage	Annual Wireline System Cost: FAA Pays All Costs — Radar Plus Beacon	Annual Wireline System Cost: FAA Pays All Costs — Beacon Only	Annual Wireline System Cost: FAA Pays One-Half of Data Processing Costs[c] — Radar Plus Beacon	Annual Wireline System Cost: FAA Pays One-Half of Data Processing Costs[c] — Beacon Only
	Chicago					
FAA	Chicago	30	$183,430	$168,430	$183,430	$168,430
AFT2	Traverse City	360	214,884	199,885	141,385	149,385
FAA	LaGrange	150	197,268	182,268	197,268	182,268
FAA	Horicon	110	193,758	178,758	193,758	178,758
FAA	West Branch	150	197,268	182,268	197,268	182,268
AFT2	Hanna City[b]	110	193,758	178,758	120,258	128,258
FAA	Afton, Ia.[b]	300	210,430	195,430	210,430	195,430
			1,390,797	1,285,797	1,243,797	1,184,797
	Kansas City					
FAA	St. Louis	230	204,288	189,288	204,288	189,288
AFT2	Hutchinson	180	199,900	184,900	126,400	134,400
AF	Garden City	350	214,142	199,142	214,142	199,142
AFT2	Omaha	170	199,022	184,022	125,522	133,522
AFT2	Kirksville[b]	150	197,268	182,268	123,768	131,768
FAA	Fairfield[b]	110	193,758	178,758	193,758	178,758
FAA	Strang[b]	160	110,645	103,145	110,645	103,145
			1,319,023	1,221,523	1,098,523	1,070,023
	Memphis					
AF	Crystal Springs	220	203,410	188,410	203,410	188,410
AF	Nashville	180	199,900	184,900	199,900	184,900
FAA	Greenville[b]	120	194,635	179,635	194,635	179,635
AFT2	Walnut Ridge[b]	100	192,380	177,880	119,380	127,380
ASR	Little Rock[b]	130	195,512	180,512	195,512	180,512
			958,837	911,337	912,837	860,837

Radar Facility Classification	ARTCC Radar Site	Straight-Line Mileage	Annual Wireline System Cost: FAA Pays All Costs — Radar Plus Beacon	FAA Pays All Costs — Beacon Only	FAA Pays One-Half of Data Processing Costs[c] — Radar Plus Beacon	FAA Pays One-Half of Data Processing Costs[c] — Beacon Only
	Fort Worth					
FAA	Odessa	310	$211,172	$196,172	$211,172	$196,172
AF	Oklahoma City	180	199,900	184,900	199,900	184,900
AF	Texarkana	180	199,900	184,900	199,900	184,900
AF	Perrin AFB[b]	70	188,830	173,830	188,830	173,830
FAA	Palestine[b]	140	196,290	181,390	196,390	181,390
FAA	Elk City[b]	230	204,288	189,288	204,288	189,288
FAA	Seymour[b]	140	196,390	181,390	196,390	181,390
AF	Sweetwater[b]	200	201,655	186,655	201,655	186,655
AF	Peyote[b]	370	215,628	200,628	215,628	200,628
FAA	Strang[b]	280	121,175	113,675	121,175	113,625
			1,935,328	1,792,828	1,935,328	1,792,878
	Houston					
FAA	Crowley[b]	180	199,900	184,500	199,900	184,900
FAA	New Orleans	340	213,400	198,400	213,400	198,400
AF	Alexandria	200	201,655	186,655	201,655	186,655
AF	San Antonio	190	200,778	185,778	200,778	185,778
			815,733	755,733	815,733	755,733
	Denver					
AF	Denver	40	184,780	169,780	184,780	169,780
AF	Gallup	340	213,400	198,400	213,400	198,400
AF	Grand Junction	190	200,778	185,778	200,778	185,778
AF	Trinidad	190	200,778	184,778	200,778	185,778
AF	North Platte	230	204,288	189,288	204,288	189,288
AF	Wheatland	170	199,022	184,022	199,022	184,022
			1,203,046	1,113,046	1,203,046	1,113,046

Radar Facility Classification	ARTCC Radar Site	Straight-Line Mileage	Annual Wireline System Cost: FAA Pays All Costs — Radar Plus Beacon	FAA Pays All Costs — Beacon Only	FAA Pays One-Half of Data Processing Costs[c/] — Radar Plus Beacon	FAA Pays One-Half of Data Processing Costs[c/] — Beacon Only
	Albuquerque					
FAA	Mesa Rica	140	$196,390	$181,390	$196,390	$181,390
AF	Amarillo	290	209,552	194,552	209,552	194,552
AF	Silver City	210	202,532	187,532	202,532	187,532
FAA	El Paso	230	204,288	189,288	204,288	189,288
FAA	Phoenix	310	211,172	196,172	211,172	196,172
AFT2	Winslow[b/]	230	204,288	189,288	130,788	138,788
AFT2	Tucson[b/]	300	210,430	195,430	136,930	144,930
			1,438,652	1,333,652	1,291,652	1,232,652
	Salt Lake City					
AF	Battle Mountain	260	206,920	191,920	206,920	191,920
AF	Boise	330	212,658	197,658	212,658	197,658
AF	Rock Springs	150	197,268	182,268	197,268	182,268
AF	Lovell	340	213,400	198,400	213,400	198,400
AF	Ashton	270	207,798	192,798	207,798	192,798
AF	Cedar City	220	115,910	108,410	115,910	108,410
			1,153,954	1,071,454	1,153,954	1,071,454
	Los Angeles					
AFT2	Las Vegas	190	200,778	185,778	127,278	135,278
AFT2	Boron	50	186,130	171,130	112,630	120,630
FAA	Paso Robles	150	109,768	102,268	109,768	102,268
AFT2	Los Angeles	50	186,130	171,130	112,630	120,630
AFT2	El Centro	150	197,268	182,268	123,768	131,768
AF	Cedar City	360	127,385	119,885	127,385	119,885
			1,007,459	932,459	713,459	730,459

Radar Facility Classification	ARTCC Radar Site	Straight-Line Mileage	Annual Wireline System Cost: FAA Pays All Costs — Radar Plus Beacon	FAA Pays All Costs — Beacon Only	FAA Pays One-Half of Data Processing Costs[c/] — Radar Plus Beacon	FAA Pays One-Half of Data Processing Costs[c/] — Beacon Only
	Oakland					
FAA	Paso Robles	160	$110,645	$103,145	$110,645	$103,145
AFT2	Sacramento	80	190,180	175,180	116,680	124,680
AFT2	Red Bluff	180	199,900	184,900	126,400	134,400
FAA	Fallon	230	204,288	189,288	204,288	189,288
AF	Tonopah	270	207,797	192,797	207,797	192,797
FAA	Fortuna[b/]	230	204,288	189,288	204,288	189,288
			1,117,098	1,034,598	970,098	933,598
	Seattle					
FAA	Salem	180	199,900	184,950	199,900	184,900
AFT2	Klamath Falls	360	214,885	199,884	141,385	149,385
AFT2	Spokane	240	205,165	190,165	131,615	139,665
FAA	Condon	260	206,920	191,920	206,920	191,920
AFT2	Seattle	30	183,430	168,430	109,930	117,930
			1,010,310	935,350	789,750	783,800
	Grand Total - Case I		15,270,485	14,130,536	13,137,935	12,619,183
	Case II		21,680,281	20,087,832	18,988,223	18,358,259

See Note to Table VIII.

a/ Appear only in Case I. (Presently Programmed network).

b/ Appear only in Case II. (Hypothetical network to provide coverage to 5000' MSL or 3000' above terrain whichever is higher).

c/ At joint use sites.

THE LEAST COST SYSTEMS

In the preceding sections the discussion has centered on the development of systemwide costs according to either a microwave or wireline transmission method. While it is apparent that the all-wireline system is less costly than the all-microwave system, there is no assurance that the all-wireline system is the least costly system. The probability that a combined wireline/microwave system would provide a "least" cost system is indicated by the fact that for many individual links the microwave technique is the lesser cost alternative. Thus, the possibility of a lower total center complex cost through a combination of the two techniques exists.

DISCUSSION OF METHODOLOGY

If wireline is the lower cost option on two of four links associated with an ARTCC, the assignment of these two links to wireline requires that the cost assigned to the remaining microwave links be raised to cover their geater remaining share of the spare data processor (the one part of the ARTCC remoting facilities common to all links). In doing this the total cost of the complex may rise in spite of the fact that the wireline costs were lower in two individual cases. The objective of this exercise was to produce the lowest transmission cost for each ARTCC remoting complex. Therefore, it is conceivable that the retention of microwave on a given link within a center complex may result in a lower total center configuration cost in spite of the fact that on an individual link basis wireline may be the lower cost option. The general rule for this investigation was to determine whether the conversion of a link (or links) to wireline transmission resulted in a saving at least as great as the resultant loss due to the greater cost assignable to the remaining wireline links. A general algebraic expression of this rule is as follows:

Total Savings on Links Converted to Wireline	Must be Greater Than	The Number of Remaining Links	Times
$\sum (M - T)$	$>$	$(N_M - n_T)$	X

The difference between

The new data processing cost per link and the all-microwave data processing cost per link

$$\frac{(N_M + S)\ (Cdp) - (n_T + S-1)\ (Cdp)}{N_M - n_T} - \frac{(N_M + S)\ (Cdp)}{N_M}$$

where:

- M = all microwave link cost
- T = wireline link cost
- N_M = total number of links
- n_T = proposed number of wireline links
- Cdp = cost per link of data processing under all-microwave option
- S = number of spare data processors required under all-microwave configuration

This general expression is predicated on the operating premise that the only variation in the cost of the remaining links is attributable to the assignment of a greater share of the data processing costs.

Table XVII presents the result of this "least cost" system determination. In order to properly interpret the results indicated in this table, it must be kept in mind that the figures presented are merely the results of operating on previously evolved basic unit costs. Therefore, the results of these operations are no more accurate than the original estimates. It is virtually impossible to assess the extent of the error of estimate involved. However, while every effort has been made to provide as accurate estimates as was possible within the scope of this analysis, cost comparisons which are within five to seven percent of one another cannot be considered definitive.

TABLE XVII

TOTAL LINK COSTS APPLICABLE TO THE LEAST COST SYSTEMS

ARTCC Radar Site	Presently Programmed System			Hypothetical System		
	Transmission Method[c]	Raw Radar Plus Beacon	Beacon Only	Transmission Method[c]	Raw Radar Plus Beacon	Beacon Only
Boston						
Bucks Harbor	T	$205,165	$190,165	T	$205,165	$190,165
Boston	T	166,000	150,000	M	148,405	134,072
Saratoga Springs	M	195,500	179,500	M	182,931	168,598
Watertown[b]	-	-	-	M	243,163	228,830
		566,665	519,665		779,664	721,665
New York						
Boston[a]	M	200,000	185,667	-	-	-
Montauk	M	159,500	145,167	T	187,480	172,480
Palermo	M	211,000	196,667	T	195,512	180,512
Pottersville[b]	-	-	-	T	201,655	186,655
		570,500	527,501		584,647	539,647
Washington						
Cherry Point[b]	-	-	-	T	208,675	193,675
Benson	M	242,000	228,500	T	206,042	191,042
Cape Charles	M	201,000	187,500	M	201,000	187,500
Roanoke	M	181,500	168,000	M	182,000	168,500
Kessel[b]	-	-	-	M	156,242	142,742
Washington	M	112,500	99,000	M	112,500	99,000
		737,000	683,000		1,066,459	982,459

ARTCC Radar Site	Presently Programmed System			Hypothetical System		
	Transmission Method[c]	Raw Radar Plus Beacon	Beacon Only	Transmission Method[c]	Raw Radar Plus Beacon	Beacon Only
Jacksonville						
Charleston	M	$235,500	$221,167	T	$200,778	$185,778
Valdosta	M	147,000	132,667	M	147,000	132,667
Jacksonville	M	126,000	111,667	M	126,000	111,667
Beaufort	-	-	-	M	197,075	182,742
Dauphin Island	T	217,111	202,112	T	217,111	202,112
Tyndall AFB[b]	T	203,410	188,410	T	203,410	188,410
		929,021	856,023		1,091,374	1,003,376
Miami						
Patrick AFB	T	199,022	184,022	T	199,022	184,022
Tampa	T	201,655	186,655	T	201,655	186,655
Cross City[b]	-	-	-	T	212,658	197,658
		400,677	370,677		613,335	568,335
Cleveland						
Dansville[a]	T	200,778	185,778	-	-	-
Phillipsburg[b]	-	-	-	M	200,495	186,995
Detroit	T	191,530	176,530	M	155,500	142,000
Pittsburgh	T	195,512	180,512	M	170,500	157,000
Lockport[b]	-	-	-	M	221,670	208,170
		587,820	542,820		748,165	694,165
Indianapolis						
New Harmony[b]	-	-	-	M	170,042	156,642
Lynch	T	207,798	192,798	T	207,798	192,798
London	T	197,268	182,268	M	169,500	156,000
Huntington[b]	-	-	-	T	202,532	187,532
Lexington[b]	-	-	-	M	180,497	166,997
Rockville[b]	-	-	-	M	115,552	102,052
		405,066	375,066		1,046,021	962,021

ARTCC Radar Site	Presently Programmed System: Transmission Method[c]	Presently Programmed System: Raw Radar Plus Beacon	Presently Programmed System: Beacon Only	Hypothetical System: Transmission Method[c]	Hypothetical System: Raw Radar Plus Beacon	Hypothetical System: Beacon Only
Atlanta						
Atlanta	M	$177,000	$161,000	M	$139,500	$126,000
Montgomery	M	193,390	177,390	M	167,500	154,000
Lynch	T	206,920	191,920	T	206,920	191,920
McCormick[b]	-	-	-	M	173,681	160,181
Charlotte	T	204,288	189,288	T	204,288	189,288
Birmingham[b]	-	-	-	M	193,624	180,124
Crossville[b]	-	-	-	T	201,655	186,655
		781,598	719,598		1,287,168	1,188,168
Minneapolis						
Houghton	T	206,920	191,920	T	206,920	191,920
Minneapolis	T	183,430	168,430	M	151,000	135,000
DeSoto[b]	-	-	-	M	203,920	187,920
		390,350	360,350		561,840	514,840
Chicago						
Chicago	M	113,500	100,000	M	113,500	100,000
Traverse City	T	214,885	199,885	T	214,885	199,885
LaGrange	M	183,400	170,000	M	183,400	170,000
Horicon	M	154,500	141,000	M	154,500	141,000
West Branch	M	187,000	173,500	T	197,268	182,286
Hanna City[b]	-	-	-	M	165,549	152,049
Afton, Ia.[b]	-	-	-	T	210,430	195,430
		853,385	784,385		1,239,632	1,140,650

ARTCC Radar Site	Presently Programmed System: Transmission Method[c]	Presently Programmed System: Raw Radar Plus Beacon	Presently Programmed System: Beacon Only	Hypothetical System: Transmission Method[c]	Hypothetical System: Raw Radar Plus Beacon	Hypothetical System: Beacon Only
Kansas City						
St. Louis	T	$204,288	$189,288	T	$204,288	$189,288
Hutchinson	T	199,900	184,900	M	195,500	182,000
Garden City	T	214,142	199,142	T	214,142	199,142
Omaha	T	199,022	184,022	M	195,500	182,000
Kirksville[b]	-	-	-	M	164,877	151,387
Fairfield[b]	-	-	-	M	184,493	170,993
Strang[b]	-	-	-	T	110,645	103,145
		817,352	757,352		1,269,445	1,177,955
Memphis						
Crystal Springs	T	203,410	188,410	T	203,410	188,410
Nashville	T	199,900	184,900	M	197,500	184,000
Greenville[b]	-	-	-	M	154,739	141,239
Walnut Ridge[b]	-	-	-	M	159,242	145,742
Little Rock[b]	-	-	-	M	173,475	159,975
		403,310	373,310		888,366	819,362
Fort Worth						
Odessa	T	211,172	196,172	T	211,172	196,172
Oklahoma City	T	199,900	184,900	M	183,500	170,000
Texarkana	T	199,900	184,900	T	199,900	184,900
Perrin AFB[b]	-	-	-	M	115,552	102,052
Palestine[b]	-	-	-	M	166,420	152,920
Elk City[b]	-	-	-	T	204,288	189,288
Seymour[b]	-	-	-	M	166,420	152,920
Sweetwater[b]	-	-	-	T	201,655	186,655
Peyote[b]	-	-	-	T	215,628	200,628
Strang[b]	-	-	-	T	121,175	113,675
		610,972	565,972		1,785,710	1,649,210

ARTCC Radar Site	Presently Programmed System			Hypothetical System		
	Transmission Method[c]	Raw Radar Plus Beacon	Beacon Only	Transmission Method[c]	Raw Radar Plus Beacon	Beacon Only
Houston						
Crowley[b]	-	-	-	T	$199,900	$184,900
New Orleans	T	213,400	198.400	T	213,400	198,400
Alexandria	T	201,655	186,655	T	201,655	186,655
San Antonio	T	200,778	187,778	T	200,778	185,778
		615,833	570,833		815,733	755,733
Denver						
Denver	T	184,780	169,780	T	184,780	169,780
Gallup	T	213,400	198,400	T	213,400	198,400
Grand Junction	T	200,778	185,778	T	200,778	185,778
Trinidad	T	200,778	185,778	T	200,778	185,778
North Platte	T	204,288	189,288	T	204,288	189,288
Wheatland	T	199,022	184,022	T	199,022	184,022
		1,203,406	1,113,046		1,203,046	1,113,046
Albuquerque						
Mesa Rica	T	196,390	181,390	T	196,390	181,390
Amarillo	T	209,552	194,552	T	209,552	194,552
Silver City	T	202,532	187,532	T	202,532	187,532
El Paso	T	204,288	189,288	T	204,288	189,288
Phoenix	T	211,172	196,172	T	211,172	196,172
Winslow[b]	-	-	-	T	204,288	189,288
Tucson[b]	-	-	-	T	210,430	195,430
		1,023,934	948,934		1,438,652	1,333,652

ARTCC Radar Site	Presently Programmed System: Trans-mission Method[c]	Raw Radar Plus Beacon	Beacon Only	Hypothetical System: Trans-mission Method[c]	Raw Radar Plus Beacon	Beacon Only
Salt Lake City						
Battle Mountain	T	$206,920	$191,920	T	$ 206,920	$191,920
Boise	T	212,658	197,658	T	212,658	197,658
Rock Springs	T	197,268	182,268	T	197,268	182,268
Lovell	T	213,400	198,400	T	213,400	198,400
Ashton	T	207,798	192,798	T	207,798	192,798
Cedar City	T	115,910	108,410	T	115,910	108,410
		1,153,954	1,071,454		1,153,954	1,071,454
Los Angeles						
Las Vegas	T	200,778	185,778	T	200,778	185,778
Boron	M	181,000	165,000	M	181,000	165,000
Paso Robles	T	109,768	102,268	T	109,768	102,268
Los Angeles	M	166,000	150,000	M	166,000	150,000
El Centro	T	197,268	182,268	T	197,268	182,268
Cedar City	T	127,385	119,885	T	127,385	119,885
		982,199	905,199		982,199	905,199
Oakland						
Paso Robles	T	110,645	103,145	T	110,645	103,145
Sacramento	T	190,180	175,180	T	190,180	175,180
Red Bluff	T	199,900	184,900	T	199,900	184,900
Fallon	T	204,288	189,288	T	204,288	189,288
Tonopah	T	207,797	192,797	T	207,797	192,797
Fortuna[b]	T	-	-	T	204,288	189,288
		912,810	845,310		1,117,098	1,034,598

ARTCC Radar Site	Presently Programmed System			Hypothethical System		
	Transmission Method[c]	Raw Radar Plus Beacon	Beacon Only	Transmission Method[c]	Raw Radar Plus Beacon	Beacon Only
Seattle						
Salem	T	$199,900	$184,950	T	$199,900	$184,950
Klamath Falls	T	214,885	199,885	T	214,885	199,885
Spokane	T	205,165	190,165	T	205,165	190,165
Condon	T	206,920	191,920	T	206,920	191,920
Seattle	T	183,430	168,430	T	183,430	168,430
		1,010,300	935,350		1,010,300	935,350
Grand Total		14,955,792	13,824,845		20,682,808	19,110,885

See Note Table VIII.

a/ Appear only in Case I. (Presently programmed network).

b/ Appear only in Case II. (Hypothetical network to provide coverate to 5000' MSL or 3000' above terrain whichever is higher.)

c/ Key: T = Wireline link
M = Microwave link

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3. Costs of Public Communication Services: Project 416.0.4; The MITRE Corporation, Bedford, Mass.

4. Radar Air Traffic Control. FAA Office of Personnel and Training.

5. Federal Aviation Agency Specification - Radar Microwave Link System; FAA-R-1119c; December 15, 1959.

In addition to the above, references are made by means of notes to the text concerning other important sources of information.

APPENDIX

INVENTORY OF MICROWAVE REPEATER SITES

(Sites by Link by Classification)

ARTCC Radar Site	Straight-Line Mileage	Classification of Terminal Pair	No. & Classification of Repeater Sites	Total No. of Repeaters
Boston				
Bucks Harbor	240	1 RT	4 UBT, 1 ET, 2 RBT, 1 RB, 1 UBT	9
Boston	40	1 UT	2 UBT	2
Saratoga Springs	130	1 RT	1 UBT, 2 EBT, 1 EB	4
Watertown[b]	280	1 ET	1 UO, 3 EBT, 3 EO 1 RBT	8
New York				
Benton[a]	170	1 RT	2 UBT, 1 UT, 3 EBT	6
Montauk	60	1 RT	4 EBT	4
Palermo	130	1 UT	2 UBT, 4 EBT, 1 ET	7
Pottersville[b]	200	1 ET	1 UBT, 2 UO, 1 EBT, 1 RBT	9
Washington				
Cherry Point[b]	280	1 ET	1 UBT, 3 EBT, 5 EO, 1 RBT	10
Benson	250	1 RT	1 UBT, 8 EBT, 1 EB	10
Cape Charles	160	1 EBT	1 UT, 2 EBT, 3 EO, 1 RBT	7
Roanoke	150	1 ET	6 EBT	6
Kessel[b]	110	1 RT	2 EBT, 1 RBT	3
Washington	40	1 UT	1 ET	1

ARTCC Radar Site	Straight-Line Mileage	Classification of Terminal Pair	No. & Classification of Repeater Sites	Total No. of Repeaters
Jacksonville				
Charleston	190	1 ET	1 UBT, 4 EBT, 3 RBT	8
Valdosta	80	1 UBT	3 EBT	3
Jacksonville	30	1 UT	1 UBT	1
Beaufort[b]	160	1 RT	1 UO, 2 EO, 2 RO	5
Dauphin Island	390	1 RBT	2 EBT, 4 ET, 5 EO 5 RBT	16
Tyndall AFB	220	1 ET	6 EBT, 1 EB, 3 EO	10
Miami				
Patrick AFB	170	1 ET	1 UBT, 6 EBT	7
Tampa	200	1 UBT	1 UBT, 1 UO, 2 EBT, 1 ET, 4 EO	9
Cross City[b]	330	1 ET	1 UT, 5 EBT, 5 ET, 1 RBT	12
Cleveland				
Dansville[a]	190	1 RBT	2 UBT, 6 EBT, 1 RB	9
Philipsburg[b]	220	1 ET	2 UO, 3 EBT, 3 EO	8
Detroit	90	1 UBT	1 UBT, 3 EBT	4
Pittsburgh	130	1 UT	2 UBT, 3 EBT	5
Lockport[b]	220	1 UT	1 EBT, 7 ET	8
Indianapolis				
New Harmony[b]	150	1 RT	4 EBT	4
Lynch	270	1 RB	1 UO, 5 EBT, 4 EB	10
London	150	1 UBT	1 UBT, 3 EBT, 1 EB	5
Huntington[b]	210	1 ET	3 EBT, 6 EO	9
Lexington[b]	120	1 UT	3 EBT, 2 ET	5
Rockville[b]	80	1 ET	1 EBT	1

ARTCC Radar Site	Straight-Line Mileage	Classification of Terminal Pair	No. & Classification of Repeater Sites	Total No. of Repeaters
Atlanta				
Atlanta	40	1 ET	2 EBT, 1 EB	3
Montgomery	140	1 EBT	5 EBT	5
Lynch	260	1 RT	1 UO, 5 EBT, 6 EO 1 RBT	13
McCormick[b/]	130	1 ET	5 ET	5
Charlotte	230	1 UBT	8 EBT	8
Birmingham	140	1 UT	3 EBT, 3 EO	6
Crossville[b/]	200	1 RT	4 EBT, 3 EO, 2 RBT	9
Minneapolis				
Houghton	260	1 RT	1 UBT, 3 EBT, 1 EB, 3 RBT, 1 RB	9
Minneapolis	30	1 UT	1 UBT	1
De Soto[b/]	140	1 ET	4 EBT	4
Chicago				
Chicago	30	1 UT	1 UBT	1
Traverse City	360	1 RT	2 UO, 5 EBT, 2 EB, 1 ET, 1 EO, 1 RBT	12
LaGrange	150	1 ET	1 UBT, 1 UT, 3 EBT, 1 EB	6
Horicon	110	1 ET	1 UBT, 3 EBT	4
West Branch	150	1 RT	1 UBT, 1 UO, 3 EBT, 1 EB	6
Hanna City[b/]	110	1 ET	1 UT, 3 EBT	4
Afton, Ia.[b/]	300	1 ET	1 UB, 1 UO, 5 EBT, 5 EO	12

ARTCC Radar Site	Straight-Line Mileage	Classification of Terminal Pair	No. & Classification of Repeater Sites	Total No. of Repeaters
Kansas City				
St. Louis	230	1 UBT	1 UBT 8 EBT	9
Hutchinson	180	1 ET	7 EBT	7
Garden City	350	1 ET	5 EBT, 1 EB, 7 EO	13
Omaha	170	1 ET	7 EBT	7
Kirksville[b/]	150	1 ET	1 UO, 3 EBT	4
Fairfield[b/]	110	1 ET	1 UT, 2 EBT	3
Strang[b/]	160	1 ET	4 EBT	4
Memphis				
Crystal Springs	220	1 EBT	1 UBT, 6 EBT, 2 EB	9
Nashville	180	1 UT	1 UBT, 6 EBT	7
Greenville[b/]	120	1 ET	1 UO, 1 EBT, 2 EO	4
Walnut Ridge[b/]	100	1 RT	2 EBT, 1 RBT	3
Little Rock[b/]	130	1 UT	3 EBT, 1 RBT	4
Fort Worth				
Odessa	310	1 EBT	1 UBT, 7 EBT, 3 EB	11
Oklahoma City	180	1 UT	1 UBT, 5 EBT	6
Texarkana	180	1 ET	1 UBT, 6 EBT	7
Perrin AFB[b/]	70	1 ET	1 EBT	1
Palestine[b/]	140	1 ET	4 EBT	4
Elk City[b/]	230	1 ET	1 UO, 5 EBT, 1 EO, 1 RBT	8
Seymour[b/]	140	1 ET	4 EO	4
Sweetwater[b/]	200	1 ET	1 UO, 7 ET	8
Peyote[b/]	370	1 ET	1 UT, 2 EBT, 7 ET, 3 EO	13
Strang[b/]	280	1 ET	1 UT, 5 UO, 1 ET, 2 EO	9

ARTCC Radar Site	Straight-Line Mileage	Classification of Terminal Pair	No. & Classification of Repeater Sites	Total No. of Repeaters
Houston				
New Orleans	340	1 UT	1 UBT, 8 EBT, 4 RBT	13
Alexandria	200	1 UT	1 UO, 2 EBT, 4 EO, 2 RO	9
San Antonio	190	1 UT	8 EBT	8
Crowley[b]	180	1 ET	1 UT, 3 ET, 2 RT	6
Denver				
Denver	40	1 UT	1 UBT	1
Gallup	340	1 RB	1 EBT, 1 ET, 3 EO, 9 RBT, 1 RT, 1 RO, 1 DBT, 1 DB	18
Grand Junction	190	1 RB	1 EBT, 1 RBT, 6 DBT, 1 DT	9
Trinidad	190	1 RT	3 EBT, 1 ET, 2 RBT, 1 RB	7
North Platte	230	1 ET	1 UT, 8 EBT	9
Wheatland	170	1 RT	1 EBT, 1 EB, 1 ET, 3 RBT, 1 RB	7
Albuquerque				
Mesa Rica	140	1 RT	4 RBT	4
Amarillo	290	1 EO	3 EBT, 1 ET, 1 EO, 1 RBT, 4 RO	10
Silver City	210	1 DT	12 RBT	12
El Paso	230	1 UT	1 EBT, 1 RT, 8 RO	10
Phoenix	310	1 RT	1 ET, 4 RBT, 3 RB, 12 RO	20
Winslow[b]	230	1 RT	4 EBT, 3 RBT	7
Tucson[b]	300	1 ET	1 EO, 16 RO	17

ARTCC Radar Site	Straight-Line Mileage	Classification of Terminal Pair	No. & Classification of Repeater Sites	Total No. of Repeaters
Salt Lake City				
Battle Mountain	260	1 DT	1 UB, 1 EBT, 3 EB, 6 RBT, 2 RB	13
Boise	320	1 DT	1 UO, 1 EO, 10 RBT, 1 RO	13
Rock Springs	150	1 DT	2 RBT, 2 RB, 2 DBT	6
Lovell	340	1 DT	3 RBT, 2 RT, 2 RO, 5 DBT	12
Ashton	270	1 DT	3 ET, 4 RBT, 3 RO, 1 RO	11
Cedar City	220	1 DT	1 EBT, 7 RBT, 1 RB, 1 DBT	10
Los Angeles				
Las Vegas	190	1 DT	1 UBT, 3 RBT, 4 DBT	8
Boron	50	1 DT	1 EBT, 1 DT	2
Paso Robles	150	1 RB	1 UBT, 4 EBT, 1 RBT	6
Los Angeles	50	1 UT	2 UBT	2
El Centro	150	1 DT	1 UT, 1 UO, 4 RBT, 2 DBT	8
Cedar City	360	1 DT	1 UO, 6 RBT, 2 RB, 3 RO, 1 DBT, 1 DT, 3 DO	17
Oakland				
Paso Robles	160	1 RT	6 EBT	6
Sacramento	80	1 UT	3 UBT, 1 EBT	4
Red Bluff	180	1 RT	1 UT, 2 UO, 3 EBT, 1 RBT	7
Fallon	230	1 DT	3 UO, 1 EO, 4 RBT, 1 RB, 1 DB, 1 DBT	11
Tonopah	270	1 DT	3 UT, 1 ET, 5 RBT, 5 RO, 1 DO	15
Fortuna[b/]	230	1 ET	2 UT, 1 UO, 2 EBT, 3 EO, 1 RBT, 1 RO	10

ARTCC Radar Site	Straight-Line Mileage	Classification of Terminal Pair	No. & Classification of Repeater Sites	Total No. of Repeaters
Seattle				
Salem	180	1 RBT	1 UBT, 1 UO, 5 EBT, 1 RBT	8
Klamath Falls	360	1 DT	1 UT, P-UO, 2 DBT, 1 EB, 4 ET, 4 RBT, 1 RB, 2 RT	16
Spokane	240	1 DT	6 RBT, 2 RB	8
Condon	260	1 DBT	3 RBT, 1 RB, 4 RO	8
Seattle	30	1 UT	1 UBT, 1 UO	2

P - Passive

a/ Appear only in Case I. (Presently programmed network).

b/ Appear in Case II only. (Hypothethical network to provide coverage to 5000' MSL or 3000' above terrain whichever is higher).

Key:

E = Readily accessible site with no particular construction or maintenance problems.
U = Same as above but in an urban area.
R = A site characterized by some difficulty in access and/or construction and/or maintenance.
D = Differs mainly from "R" in degree.

O = No additional building or tower required.
B = Initial or additional building construction required.
T = Initial or additional tower required.
BT = Initial or additional building and tower required.

FAA REPORTED MICROWAVE LINK ESTABLISHMENT COSTS (REPEATERS ONLY)

ARTCC Radar Site	Civil Engineering	Electrical Engineering	Construction	Installation	Total Cost
Lewiston (Benton)	$15,758	$20,000	$120,000	-	$155,758
Montauk Point	14,432	15,000	119,000	-	148,432
Benson	22,814	10,500	165,000	-	198,314
Cape Charles	22,000	20,000	171,600	-	213,600
Roanoke	17,231	29,399	121,016	-	167,646
Charleston	15,497	4,170	236,433	$5,000	261,100
Valdosta	7,450	9,034	78,183	434	95,101
Jacksonville	722	856	36,000	2,900	40,478
Patrick	3,745	-	37,232	1,041	42,018
Pittsburgh	6,051	16,500	97,500	-	120,051
Lynch (Indianapolis)	7,500	20,500	141,600	-	169,600
Lynch (Atlanta)	16,200	-	179,794	4,500	200,404
Dauphin Island	11,400	4,500	128,850	-	144,750
Charlotte	11,578	6,198	209,021	-	226,797
Chicago	625	270	15,625[b]	-	16,520
LaGrange	8,725	1,846	138,015[b]	-	148,586
Horicon	1,951	3,150	104,000[a]	-	117,101
Iowa City	10,941	1,650	117,943[a]	-	130,534

a/ Includes ½ of Maple Park Dual.

b/ Includes ½ of Downers Grove.

SOURCE: Quarterly Report, Facility Established Costs.

EXAMPLES OF TOTAL LINK REPEATER COSTS[a/]

(No trunked paths included)[b/]

Radar	Number of LMWR	Total Cost	Average $/MWR
Spokane-Seattle	8	$502,206	$62,775
Paso Robles-Oakland	6	282,051	47,008
Las Vegas-Los Angeles	8	669,867	83,733
Cedar City-Salt Lake City	10	414,188	41,419
Silver City-Albuquerque	12	383,075	31,923
Lusk-Denver	7	242,945	34,706
North Platte-Denver	9	268,469	29,829
Grand Junction-Denver	9	656,755	72,972
Houston-San Antonio	8	249,660	31,207
Texarkana-Fort Worth	7	201,745	28,820
Oklahoma City-Fort Worth	6	148,738	24,790
Odessa-Fort Worth	11	310,500	28,227
Nashville-Memphis	7	202,628	28,947
Pittsburgh-Cleveland	5	120,051	24,010
Charleston-Jacksonville	8	261,100	32,637
Valdosta-Jacksonville	3	95,101	31,700
Roanoke-Washington	10	167,646	16,765
Benson-Washington	10	198,314	19,831
Montauk-New York	3	148,432	49,477
Lewiston-New York	6	155,758	25,960
Lynch-Indianapolis	10	169,600	16,960
Jackson-Memphis	8	145,750	18,219

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a/ Includes civil and electronic engineering construction and installation costs.

b/ In some cases one repeater of the link may be dual or triple.

SOURCE: Quarterly Report, Facility Establishment Costs.

FAA REPORTED MICROWAVE TERMINAL PAIR ESTABLISHMENT COSTS

(Excludes Cost of Electronic Equipment)

ARTCC Radar Site	Civil Engineering	Electronic Engineering	Construction	Installation	Total Cost
Lewiston (Benton)	$ 692	$1,500	$ 5,658	$ 2,000	$ 9,850
Montauk Point	1,530	1,500	26,391	2,000	31,421
Benson	5,333	2,031	7,660	1,665	16,689
Cape Charles	3,000	6,000	30,000	-	39,000
Roanoke	680	1,699	1,725	2,000	6,104
Charleston	1,177	679	10,515	1,035	13,406
Valdosta	2,742	579	33,715	-	37,036
Jacksonville	3,148	3,691	13,900	126	20,865
Patrick	645	-	12,700	5,600	18,945
Pittsburgh	18,000	3,000	25,000	-	46,000
Lynch (Atlanta)	5,800	-	19,450	9,500	34,750
Dauphin Island	3,348	5,000	30,060	-	38,408
Charlotte	1,100	450	28,570	10,550	40,670

SOURCE: Quarterly Report, Facility Establishment Costs.

FAA REGIONAL MAINTENANCE ESTIMATES[a]

(For Microwave Repeaters and Terminals)

Repeaters	Total Cost	No. of Sites	Cost Categories Not Included
Kenansville, Fla.	$11,676	1	2, 5, 10, 12, 13
Indiantown, Fla.	11,728	1	Same
Davis, Fla.	11,125	1	Same
Ft. Drum, Fla.	11,928	1	Same
Del Ray Beach, Fla.	11,434	1	Same
McDill AFB to Patrick AFB-Miami Link	51,011	4	Same
West Palm Beach, Fla.	12,025	1	Same
Palermo, N.J.	12,034	1	Same
Atlantic City, N.J.	9,958	1	2, 5, 10, 12, 13, 7
Warren Grove, N.J.	10,753	1	2, 5, 10, 12, 13
Imlaystown, N.J.	11,858	1	Same
South River, N.J.	11,968	1	Same
St. Francis, N.Y.	12,879	1	Same
Ashley Hall, S.C.	17,649	1	Same
Jacksonboro, S.C.	18,368	1	Same
Yenasee, S.C.	18,845	1	Same
Hardyville, S.C.	17,944	1	Same
Burroughs, Ga.	17,686	1	Same
South Newport, Ga.	18,433	1	Same
Thallman, Ga.	18,066	1	Same
Seals, Ga.	18,121	1	Same
Garden City-Kansas City	11,794	1	Same
Condon-Seattle	151,220	10	Same
Fallon-Oakland	182,416	12	Same
Cedar City-Los Angeles	285,013	19	Same
Terminals			
McDill AFB (Tampa)-Miami	30,546	2	2, 3, 5, 7, 10, 12, 13
Palermo-New York	15,736	1	2, 7, 8, 5, 9, 12, 13
New York-New York	15,737	1	2, 8, 5, 10, 12, 13
Charleston, S.C.-Jacksonville	23,766	2	2, 5, 7, 8, 10, 12, 13
Garden City-Kansas City	17,505	1	Same
Condon-Seattle	49,519	2	Same
Fallon-Oakland	49,519	2	Same[b]
Cedar City-Los Angeles	49,519	2	Same

a/ No equipment spares included.

b/ Includes $4,000 in trucks and snow vehicles.

Note: Cost Categories

1. Personal Services
2. Caretaker/Station Laborers
3. Overtime
4. Travel
5. AF-200 Stocks and Stores
6. Transportation of things
7. Rents, Communications Utilities
8. Other Contractor Devices
9. Facility Supply Items
10. Flight Check
11. Additional Support Cost
12. Special Maintenance Property
13. Replacement Test and Working Equipment